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TEST METHODS FOR INDUCTION FURNACES WITH SUBMERGED CHANNELS

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TEST METHODS FOR INDUCTION FURNACES WITH SUBMERGED CHANNELS

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Indian Standard

TEST METHODS FOR INDUCTION FURNACES WITH SUBMERGED CHANNELS

0. FOREWORD

0.1 This Indian Standard was adopted by the Indian Standards Institution on 14 December 1978, after the draft finalized by the Industrial Electroheating Equipment Sectional Committee had been approved by the Electrotechnical Division Council.

0.2 This standard covers the test methods to determine the essential parameters and technical characteristics of electro-heating installations comprising the induction furnaces with submerged channel.

0.3 In formulating this standard, assistance has been derived from IEC Publication 396 (1972) 'Test methods for induction furnaces with submerged channels' issued by International Electrotechnical Commission.

0.4 For the purpose of deciding whether a particular requirement of this standard is complied with, the final value, observed or calculated, expressing the result of a test, shall be rounded off in accordance with IS : 2-1960*. The number of significant places retained in the rounded off value should be the same as that of the specified value in this standard.

1. SCOPE

1.1 This standard specifies the methods of tests for electro-heating installations comprising industrial induction furnaces with submerged channels for the melting of metals and keeping them molten, operating at mains frequency.

2. TERMINOLOGY

2.0 For the purpose of this standard, the following definitions shall apply.

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*Rules for rounding off numerical values (*revised*).

2.1 Electro-heating Installation with Induction Furnace with Submerged Channel — Complete assembly of an electro-heating device and the electrical and mechanical equipment necessary for the operation and utilization of an induction furnace with submerged channel.

The electrical equipment comprises, in particular, the conduits and switchgear in the power, control, and regulating circuits, and the transformer(s), when the device is supplied by its own transformer(s).

2.2 Power of an Electro-heating Installation (Apparent Power P_{1t} in kVA or Active Power P_{1a} in kW) — The electric power measured at the input of the supply line, the voltage being set at its rated value.

2.3 Power-Factor of an Electro-heating Installation (cos ϕ) — The ratio of the active power to the apparent power, measured at the input of the supply line.

2.4 Holding Power of the Heel Metal of an Electro-heating Installation P_b in kW — Active power consumed by the installation, in order to maintain the heel metal at the rated temperature.

2.5 Holding Power of an Electro-heating Installation P_{an1} in kW — Active power consumed by the installation, in order to maintain the total charge at the rated temperature.

2.6 Specific Energy Consumption e — Ratio of the total amount of electric energy (kWh) consumed by an electro-heating installation for heating, melting and possibly overheating the charge, plus all energy losses, to the weight of the useful charge (kg).

2.7 Output of the Furnace of an Electro-heating Installation g — Ratio of weight of useful charge (kg) at its final temperature to the total time (h) for heating, melting and possibly overheating.

2.8 Rated Values of an Electro-heating Installation — The rated values of an installation are those for which it is designed:

a) Rated power of an electro-heating installation, P_n; and

b) Rated voltage of an electro-heating installation, U_n.

2.9 Induction Furnace with Submerged Channel — Melting or holding furnace, with closed magnetic circuit, in which the charge, heated by induced currents, is arranged in one or several channels (vertical, inclined or horizontal) surmounted by a chamber containing the metal.

2.10 Magnetic Core of an Induction Furnace — Closed core of transformer laminations, creating a low-reluctance path for the magnetic flux. A furnace may have one or several cores.

2.11 Channel of an Induction Furnace — Channel made of refractory or other material providing a closed loop around the magnetic core. The furnace may have one or more channels.

2.12 Inductor of an Induction Furnace — Coil on magnetic core intended to be connected to a source of ac supply and generate an alternating magnetic flux in this core. The furnace may comprise one or more inductors.

2.13 Induction Unit — Constructional assembly of the magnetic core of the channel (made of refractories), the inductor, and of the metal casing with or without thermal insulation. The furnace may have one or more induction units.

Induction units are usually exchangeable.

2.14 Heating Circuit of Induction Furnace — Closed electrical circuit formed by the charge of metal situated in the channel and in the crucible of the furnace.

2.15 Crucible of an Induction Furnace — Crucible of refractory material in which the charge is placed.

2.16 Useful Capacity of Furnace V_u — Volume of the molten metal which can be withdrawn from the furnace without risk of breaking the heating circuit, the furnace being within the normal tilting limits in m^3.

2.17 Useful Charge G — Weight of molten metal corresponding to the useful capacity of the furnace in kg.

2.18 Capacity of Heel Metal V_b — Minimum volume of molten metal in the furnace required to ensure continuity of the heating circuit, the furnace being in normal tilting limits and in normal position in m^3.

2.19 Heel Metal G_b — The weight corresponding to the capacity of heel metal in kg.

2.20 Total Capacity of a Furnace V_t — Sum of useful capacity and the capacity of heel metal in m^3.

2.21 Total Charge of a Furnace G_t — Sum of the useful charge and the heel metal in kg.

2.22 Voltage of an Induction Furnace U — Voltage across the terminals of the furnace inductor in volts.

2.23 Furnace Coil Current I — Current drawn by the inductor or the system of inductors of a furnace at rated voltage in amps.

2.24 No-Load Furnace Coil Current I_0 — Furnace coil current without metal at rated voltage in amps.

2.25 Charge Temperature θ — The temperature of the useful charge volume in °C.

2.26 Final Charge Temperature θ_{fcb} — The temperature which the charge should reach directly before tapping in °C.

2.27 Outlet Temperature of Coolant (Air, Water) θ_f — Temperature of coolant when leaving the furnace operating under rated conditions in °C.

2.28 Ambient Temperature θ_a — Air temperature outside furnace at a point where heat radiation or natural convection exert no influence in °C.

2.29 Reference Ambient Temperature θ_r — Ambient temperature in °C to which all characteristic data of a furnace are referred.

2.30 Furnace Duty in Rated Conditions (Rated Furnace Duty) — Operation at the rated values (voltage, frequency and rated capacity).

2.31 Hot State of Furnace — State of a furnace after the charge attains the final temperature in the thermal steady-state of the furnace.

2.32 Thermal Steady-State of a Furnace — Thermal state in which the whole energy input into the furnace is used for the compensation of thermal and other electrical losses.

2.33 Cold State of Furnace — Thermal state in which the temperature of the furnace constructional elements is equal to the ambient temperature.

2.34 Continuous Operation of a Furnace — Operation during which the molten charge at final temperature is continually withdrawn, and charge is continually added.

2.35 Intermittent Duty of a Furnace — Duty during which the new charge is only fed in after the tapping of the preceding useful charge.

2.36 Furnace Coil Power (Apparent P_f **kVA or Active** P_a **kW)** — Electric power input (apparent or active) of the charged furnace measured at the inductor terminals.

2.37 Furnace Coil Power-Factor, Cos ϕ — Ratio of the active power to the apparent power of a furnace.

2.38 No-Load Power of Furnace Coil P_0 — Active power input of furnace without charge, measured at the inductor terminals in kW.

2.39 Rated Values of a Furnace — The rated values of a furnace are those for which the furnace is designed: rated useful furnace capacity G_{bu}, rated total furnace capacity G_{tu}, rated induction furnace voltage U_n, rated furnace power, P_n.

2.40 Rated Frequency f_n — The frequency for which an electrothermal appliance is built and marked in Hz.

2.41 Rated Voltage U_n — The voltage used in the specification of a machine or apparatus, and from which the test conditions and the voltage limits for the use of the machine or apparatus are determined in volts.

3. TESTS

3.1 List of Tests — For the assessment of an electro-heating installation containing a furnace, the following tests shall be performed in the order given below:

a) Measurement of power and of power factor of the electro-heating installation (*see* **3.3**);

b) Determination of holding power of the electro-heating installation (*see* **3.4**);

c) Determination of specific energy consumption and output of the electro-heating installation (*see* **3.5**);

d) Measurement of electrical parameters of inductor of furnace (*see* **3.6**);

e) Electrical withstand test of inductor (*see* **3.7**);

f) Determination of temperature-rise of air-cooled inductors (*see* **3.8**);

g) Measurement of temperature-rise of the coolant (*see* **3.9**);

h) Measurement of temperature of the furnace constructional elements (*see* **3.10**);

j) Measurement of temperature of charge (*see* **3.11**); and

k) Pressure test of water cooled inductors (*see* **3.12**).

3.2 General Conditions for Performing Tests — General test conditions for industrial electro-heating equipment shall be as given in IS : 9021-1978*. The tests are to be realized with a charge. The kind and size of the charge as well as the technological procedure for the melting of metals and keeping them molten have to be agreed upon between manufacturer and user.

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*General test conditions for industrial electro-heating equipment.

3.3 Measurements of Power and Power Factor of an Electro-heating Installation — This test comprises measurement of the quantities defined in **2.2** and **2.3** at the input of the installation.

3.3.1 The measurement of the active power is made by means of a (recording) wattmeter. The apparent power can be determined from the measurement of the current and the voltage. The measurements shall be carried out in the conditions specified in **3.6** for the measurement of the parameters of the inductor. The power-factor as defined in **2.37** can be calculated as ratio of the active power and the apparent power.

3.4 Determination of Holding Power of an Electro-heating Installation

3.4.1 *Heel Metal Alone* — This test shall be performed with the furnace in the hot state. The furnace, containing the heel metal, shall have been in operation for at least 24 h prior to the test, and in the case when it starts with a new lining, it shall have been in operation at least three days prior to the test. During this preliminary service, the rated temperature shall be maintained. Then, the useful charge shall be tapped, leaving the heel metal alone, and testing shall be started. During the entire duration of the test period, the final temperature of the charge shall be maintained constant (for example, by switching on and off the supply voltage or by using alternatively two adjacent taps of the regulating transformer). Apart from the temperature of the charge, the energy consumption of the furnace and the time are measured. The energy shall be measured at the input with an electric energy meter. The holding power is calculated by dividing the energy by the time.

3.4.2 *Total Charge* — This test shall be performed under the same conditions as **3.4.1** but with the total charge in the furnace.

3.5 Determination of Specific Energy Consumption and Output of an Electro-heating Installation

3.5.1 *Intermittent Duty*

a) For melting furnaces, the measurement is started after the furnace has been in service for at least 24 h. The furnace with heel metal at final temperature and supplied with a voltage of rated value and rated frequency, shall be gradually loaded with a charge of defined form and chemical composition until the rated useful charge is reached.

   During the service of the furnace, the electric energy consumed by the furnace shall be measured by means of an electric energy meter, connected to the input of the supply line. Also, the time during which the furnace is switched on (that is the time of heating of the charge) and occasionally the charge temperature (at the beginning of the measurement and before each tapping of the charge) shall be measured.

Intervals when the furnace is switched off shall be recorded, but cannot be taken into account for the calculation of the furnace output and the energy consumption. The measurement of the temperature at the beginning of test serves to determine the time when the sump metal reaches the rated temperature, and the measurements of temperature preceding the tapping are intended to prevent excessive overheating of the charge which should be tapped directly after reaching the final temperature. These furnaces are not switched off during those periods of inoperation. The holding power is fed to the furnace to maintain the temperature. Both, time and energy consumption for this periods should be excluded for the calculation purposes for establishing the furnace specific energy consumption.

The melting and overheating being completed, the useful charge shall be tapped, and, at least three more identical successive melts shall be carried out.

The specific energy consumption is calculated by dividing the energy consumed during the described cycle of measurements by the weight of the charge furnished by the furnace during this time.

The output of the furnace is calculated by dividing the weight of the charge furnished by the furnace during the described cycle of measurements by the duration of this cycle of measurements.

b) For furnaces intended for holding and overheating, the specific energy consumption and the output of the furnace are determined in the manner indicated above. The specific energy consumption and the output of the furnace are determined from the measurements of the energy input, the duration of holding or overheating, and the weight of the charge to be held or overheated. At least three melts shall be made.

3.5.2 *Continuous Duty*

a) For melting furnaces, the measurement is started after the furnace has been in service for at least 24 h, at the time when the furnace contains the rated charge quantity at final temperature.

The furnace shall be supplied at its rated voltage and at rated frequency and operated by continuously withdrawing from the furnace the molten charge at final temperature, and continuously adding a charge of defined physical and chemical composition. During the service of the furnace, the electric energy consumption shall be measured by means of an electric energy meter, connected to the input of the supply line. Also, the time during which the furnace is switched on (that is, the time of heating the charge) and the temperature of the charge (at the beginning of the measurement and during melting at least every 20 minutes) shall be measured.

The measurement of the temperature at the beginning of the test serves to determine the time when the charge reaches the rated temperature, and the later measurements are to prevent excessive overheating of the charge, which should be withdrawn directly after reaching the final temperature.

The measurements cited above shall be continued for a time sufficient for melting a quantity equal to at least three times the rated useful charge, and terminated with the same charge quantity in the furnace and the same charge temperature as when they began.

The specific energy consumption is calculated by dividing the electric energy consumed during the described measuring cycle by the weight of charge furnished by the furnace during this time.

The output of the furnace is calculated by dividing the weight of the charge furnished by the furnace during the described measuring cycle by the total time of duration of this cycle.

b) For holding and overheating furnaces, **3.5.1**(b) is applicable.

3.6 Measurement of Electrical Parameters of the Inductor of the Furnace — This test comprises measurements of the voltage of the furnace and of currents of the furnace inductors under on-load and no-load conditions and of the active furnace power under on-load and no-load conditions and of the power-factor of the furnace.

3.6.1 These measurements shall be carried out in the hot state of the furnace and at rated duty.

3.7 Electrical Withstand Test of the Inductor — This test shall be performed with a substantially sinusoidal voltage at the rated frequency of the furnace. The test voltage shall be applied progressively for 10 seconds, and maintained for 1 min between components which are live when the furnace is in operation, and all metal parts accessible to touch, connected together and earthed.

3.7.1 The electrical withstand test of air-cooled furnaces is performed before the refractory lining is fitted at a voltage of $2U_n + 1\,000$ V (where U_n is the rated voltage).

3.7.2 A second test shall be performed in hot state of the furnace. The value of the voltage for this test is 80 percent of that for the preceding one.

3.7.3 The electrical withstand test for water-cooled furnaces is performed before the refractory lining is fitted, in the cold state only, with the cooling water disconnected so that the components which are live during service will not be connected electrically to the metal housing of the furnace via the water.

3.8 Determination of Temperature-Rise of the Air-Cooled Inductors — The temperature-rise of air-cooled inductors is determined on the basis of the increase in electric resistance of the inductor windings, measured, for example, by the aid of a Thomson bridge immediately after switching off the current. The temperature-rise $\Delta\theta$ of copper inductors over the cooling air temperature at the inlet is determined according to the formula:

$$\Delta\theta = \frac{R_c - R_f}{R_f} \left(235 + \theta_f \right) - \left(\theta_r - \theta_f \right)$$

where

R_c = resistance of the inductor in hot state of the furnace (after test, *see* **3.5**) in ohm;

R_f = resistance of the inductor in cold state of the furnace in ohm;

θ_r = temperature of the cooling air in °C; and

θ_f = temperature of inductor in cold state of the furnace in °C.

3.8.1 The measurement of θ_r for cooling air shall be performed in the same conditions and in the same way as the measurement of **3.9**, but on the inlet of the cooling air to the furnace.

3.8.2 This temperature-rise $\Delta\theta$ shall not exceed the maximum value corresponding to the insulation class specified for air-cooled transformers. In the case of water-cooled inductors, the test is performed with the furnace charged in compliance with **3.9**.

3.9 Measurement of Temperature-Rise of the Coolant — This test shall be carried out in hot state of the furnace operating under rated conditions at the end of test (*see* **3.5**). The temperature shall be measured by aid of at least three thermometers placed at the inlet and the outlet of the coolant, reading their indications every five minutes during at least 30 min. The difference between the average value of the inlet and outlet temperature readings will give the temperature-rise value.

3.10 Measurement of Temperature of Furnace Constructional Components — This test shall be carried out directly after the test described in **3.5**. The temperature at different points of the external surfaces of the walls of the furnace housing shall be measured by means of a contact thermocouple thermometer.

3.11 Measurement of Temperature of the Charge — The charge temperature concerned is the average of three temperatures measured at three points of the charge, chosen according to the furnace design.

3.11.1 In the case of furnaces for melting metals of high melting temperatures (for example, molten iron) the measurement can be made directly under the surface of the bath in the middle of the latter.

3.11.2 This measurement shall be carried out by means of thermocouple.

3.11.3 The instrument used shall have at least a measuring accuracy of ± 15°C within the range from 300 to 1 000°C, and of ± 20°C above 1 000°C.

3.12 Pressure Test of Water Cooled Inductors — The test is to verify the leakage of the cooling water circuit and the performance of valves. The tightness of the cooling water circuits should be verified after closing the outlet of water circuits by increasing of the water pressure up to the value of 150 percent of the pressure specified by the furnace manufacturer.